USDA United States Department of Agriculture

Soil Science Curriculum

Content and lab derived from the USDA-NRCS Guides for Educators. Go to www.nrcs.usda.gov/soils for the Guides and additional pictures and diagrams. This lesson plan was adapted for South Dakota from the University of Nebraska Institute of Agriculture and Natural Resources, CROPWATCH.

January 2018

Soil Biology Respiration

Approximately 180 minutes

Soil biology respiration refers to the production of carbon dioxide when soil organisms respire. This includes respiration of plant roots, the rhizosphere, microbes and fauna.

Soil biology respiration is a key ecosystem process that releases carbon from the soil in the form of CO_2. CO_2 is acquired from the atmosphere and converted into organic compounds in the process of photosynthesis. Plants use these organic compounds to build structural components or respire them to release energy. When plant respiration occurs below-ground in the roots, it adds to soil respiration. Over time, plant structural components are consumed by the biota in the soil which then releases CO_2. When this CO_2 is released by below-ground organisms, it is considered as soil respiration.

The amount of soil respiration that occurs in an ecosystem is controlled by several factors. The temperature, moisture, nutrient content and level of oxygen in the soil can produce extremely disparate rates of respiration. These rates of respiration can be measured in a variety of methods.

Soil biology respiration rates can be largely affected by human activity. This is because humans have the ability to and have been changing the various controlling factors of soil respiration for numerous years. Tillage and fertilization by humans also has the potential to affect respiration rates.

Objectives

By the end of the lesson, students will know or be able to:

- Define soil respiration and soil microbes
- Explain the role of soil respiration in determining soil health
- Diagram the role of soil respiration in the cycle of life on earth
- List and explain inherent factors that affect soil respiration
- List and describe soil respiration management processes
- Interpret management impacts on soil respiration and soil organic matter
- Measure soil respiration and interpret data

Preparatory Work

- Place a plant cutting in a plastic baggie several hours prior to teaching this lesson so that respiration is visible

Materials

- Lab materials (see Lab Guided Notes)
- Baggie that seals
- Plant cutting

Enroll the Participants *(Approximately 4 minutes)*

Show or pass around the sealed baggie with the plant cutting inside of it. Inquire to students as to what they know about why the water droplets formed inside of the baggie even though you placed only a plant cutting inside of the baggie.

Hold up the second (empty) plastic baggie and breathe into it to demonstrate the formation of water droplets because of your breath. Again, inquire about what students know.

Content to share:

- Living organisms conduct the process of respiration.
- It's easy to see signs that a human is breathing (a rising chest or abdomen, sound of breathing, feel of breath, etc.)
- We can see that plants are breathing through the cutting in the baggie

Provide the Experience – Key Terms and Soil Health *(Approximately 5 minutes)*

Separate students into small groups of three or four.

Provide each small group with a soil sample. (It will be helpful if some of the samples have bugs, worms, crop residue or other living organisms in them.)

Instruct small groups to investigate their soil and determine what in the soil affects the respiration that occurs in the soil. Elicit student responses.

Label the Information (*Approximately 4 minutes)*

Direct students to their Guided Notes and encourage them to capture the following information.

- Soil respiration is a measure of the carbon dioxide released from the soil by microbes decomposing soil organic matter and from the respiration of plant roots.
- Soil respiration indicates soil health (soil organic matter content, soil organic matter decomposition and the level of microbial activity).
- Soil Microbes: Soil organisms that are responsible for soil respiration and many important soil processes such as nutrient cycling.
- Respiration: Release of carbon dioxide from several sources (decomposition of soil organic matter by soil microbes, and respiration from plant roots).
- Mineralization: Organic matter decomposition releasing nutrients in a plant available form that occurs during respiration.
- Ammonification: Production of ammonium from soil organic matter decomposition.
- Denitrification: Anaerobic conversion and loss of nitrate-nitrogen to nitrite and nitrogen varieties of gases.
- Nitrification: An aerobic microbial process converting soil ammonium nitrogen to plant available nitrate.

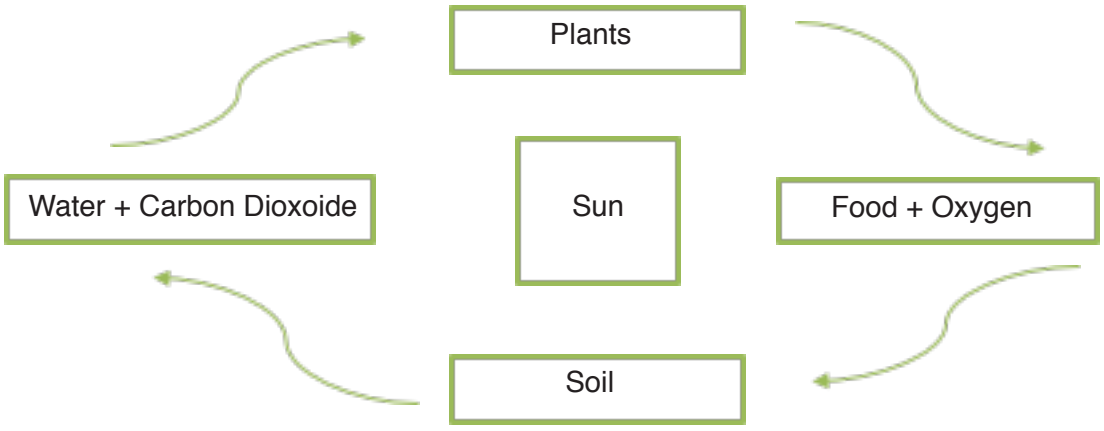
Demonstrate the Relevance *(Approximately 7 minutes)*

Instruct students to talk together and formulate ideas about how soil organic matter and respiration affect soil health.

Elicit responses, filling in the following information.

- Respiration rate can be based on the amount of soil organic matter present.
  - Soil organic matter is a food source for microbes and when microbes are present and working, respiration is higher.
  - When soil organic matter is absent or low, there is less decomposing activity.
  - Soil microbes are responsible for soil respiration and may important soil processes (such as bacteria, fungi, protozoa, algae).
  - One heaping table spoon of soil can contain over nine billion microbes, more than all the people on earth.

Share the following diagram. Encourage students to complete the diagram in their guided notes.



Provide the Experience – Factors Affecting Soil Respiration *(Approximately 5 minutes)*

Instruct students to work in small groups. Provide each small group with one of the following factors that affect soil respiration. Instruct students to discuss how their group's factor might affect soil respiration.

Factors:

Climate/Weather
Biological activity
Soil moisture
Amount and health of soil organic matter
Soil texture

Label the Information *(Approximately 10 minutes)*

- Climate/Weather
  - Cannot be changed
  - Affects temperature, moisture and indirectly affects biological activity
- Biological activity
  - Varies with the seasons and times of day
- Soil moisture
  - As moisture increases, respiration rates increase until the pores are overly saturated, resulting in lower oxygen content and lower soil organism respiration
  - Sixty percent pore space saturation (field capacity) is ideal for respiration
  - Dry soils have low respiration rates because of less support for biological activities
- Amount and health of soil organic matter
  - Affects microbe activity
- Soil texture
  - Clay – soil organic matter is "protected" from decomposition
  - Sand – too little organic matter
  - Medium texture (silt and loam) – favorable for soil respiration

Demonstrate the Relevance *(Approximately 5 minutes)*

Facilitate a discussion with your students about the larger economic effects of poor soil respiration. Depending on the demographics of your students, use references that make sense to them – farming or from the stand point of a consumer. Consider using the following questions as a guide:

How can poor soil respiration affect a farmer whose income depends on the crop grown in that soil?
How can poor soil respiration affect the prices we see for our food in the grocery store?

Provide the Experience – Soil Respiration Management *(Approximately 3 minutes)*

Continue the facilitated discussion by asking the following question:

What do you think we can do as producers and consumers to ensure a productive soil respiration rate?

Label the Information *(Approximately 7 minutes)*

Soil Respiration Management Practices

1. Leave crop residues on the soil surface.
   a. Residues with low C:N ratios decompose faster than those with high C:N ratios
   b. High residue crops + added Nitrogen = higher decomposition rates and accrual of organic matter
2. Use no-till practices.
   a. Tilling decreases soil biology which then slows decomposition of organic matter
   b. Minimize equipment use in fields
   c. Minimize farm equipment use in general when soils are wet
   d. Use designated locations for equipment traffic
3. Use cover crops.
   a. Roots provide respiration
4. Add organic matter.
   a. Nourishes microbes
5. Plant long season crops.
   a. Provides a living root for the entire growing season to maximize soil biology

Demonstrate the Relevance *(Approximately 15 minutes)*

Direct students to the following chart in their Guided Notes and instruct them to list some short term and long term impacts they can think of for each management practice and application. Use the key below to facilitate the discussion after a short time.

Table 1. Interpreting management impacts on soil respiration and Soil Organic Matter (SOM).

Management Practice	Application	Short Term Impacts	Long Term Impacts
Solid manure or organic material application	Provide additional carbon and nitrogen source for microbes to breakdown and increase biomass production.		
High residue crops or cover crops used in rotation with high C:N ratio	High C:N ratio crops and added nitrogen increase decomposition and accrual of soil organic matter.		
Tillage such as annual disking, plowing, etc.	Stirs the soil providing a temporary increase in oxygen for microbes to break down carbon sources.		
Crop residue management	Leave residue on the surface increasing ground cover to protect the soil.		
Nitrogen fertilizer or manure application	Provides nitrogen (energy) source for microbes to break down high C:N ratio residue quicker.		
Vehicle or farm equipment traffic	Compacts soil decreasing pore space, water movement, oxygen for microbes and nitrogen loss from denitrification.		

Soil Biology Respiration

Management Practice	Application	Short Term Impacts	Long Term Impacts
Solid manure or organic material application	Provide additional carbon and nitrogen source for microbes to breakdown and increase biomass production.	Increased respiration when manure begins to breakdown and increased biomass production.	Positive impact on soil structure, fertility and soil organic matter content.
High residue crops or cover crops used in rotation with high C:N ratio	High C:N ratio crops and added nitrogen increase decomposition and accrual of soil organic matter.	High C:N ratio crop residue tie up nitrogen temporarily in order to break down residue, increased soil moisture, decreased erosion.	Positive impact on long term soil health, fertility and soil organic matter content.
Tillage such as annual disking, plowing, etc.	Stirs the soil providing a temporary increase in oxygen for microbes to break down carbon sources.	Provides a flush of nitrogen, other nutrients and carbon dioxide release immediately after tillage. Increases erosion rates, decomposition rate of residue, and other carbon sources.	Declines in soil organic matter, soil health, soil fertility.
Crop residue management	Leave residue on the surface increasing ground cover to protect the soil.	Increased crop residue cover can tie up nitrogen temporarily in order to break down residue, increased soil moisture, decreased erosion and cooler soil temperatures.	Positive impact on long term soil health, fertility and soil organic matter content.
Nitrogen fertilizer or manure application	Provides nitrogen (energy) source for microbes to break down high C:N ratio residue quicker.	Temporary increase in respiration due to increased rate of breakdown of organic materials.	When managed correctly, has an overall positive impact on soil organic matter and soil health by increasing production levels and residue amounts.
Vehicle or farm equipment traffic	Compacts soil decreasing pore space, water movement, oxygen for microbes and nitrogen loss from denitrification.	Decreases respiration, yields, water infiltration and increases runoff.	Production declines, increased soil erosion and runoff, decreased soil health, compacted soils and reduced microbial activity.

Provide the Experience – Measure and Interpret Soils Respiration

(Approximately 90 minutes)

Introduce each of the laboratory supplies to the students and review the laboratory processes and procedures with the class. See the Guided Notes lab for information.

Students engage in the lab activity.

Label the Information *(Time varies)*

Students record information and answer lab questions.

Demonstrate the Relevance *(Time varies)*

Discuss with students how their activities affect soil respiration rates.

Review the Content *(Approximately 7 minutes)*

Instruct students to work in small groups to create a jingle that includes a minimum of three facts they learned during the soil respiration lesson and laboratory activity. Students share their jingle with the class.

Celebrate Student Success *(Approximately 3 minutes)*

Thank students for their engagement and participation.

Guided Notes: Soil Respiration

Notes completed by _____

Soil Microbes:

Respiration:

Mineralization:

Ammonification:

Dentrification:

Nitrification:

Soil Biology Respiration

Factors Affecting Soil Respiration

- Climate/Weather
- Biological activity
- Soil moisture
- Amount and health of soil organic matter
- Soil texture

Soil Respiration Management Practices

1. Leave crop residues on the soil surface.
2. Use no-till practices.
3. Use cover crops.
4. Add organic matter.
5. Plant long season crops.
6. Drain wet soil.

Table 1. Interpreting management impacts on soil respiration and Soil Organic Matter (SOM).

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Guided Notes: Soil Respiration Laboratory

Soil Respiration Scenario

Tom and Molly are troubled about the performance a field they recently purchased and planted to corn. The field was highly tilled with little crop residue. The equipment used on the field by the prior owner had very narrow tires, and there is no consistent path used for traveling to the irrigation pad. They are curious about what might be the problem and plan to test the soil respiration rate today.

Laboratory Supplies

- Solvita® sample jar for correct volume of soil or a 3-inch diameter aluminum cylinder and lid
- Foil-pack containing a special gel paddle
- Solvita® key for reading results
- Solvita® interpretation guide to estimate differences in soil health, respiration and potential nitrogen release
- Aluminum foil or cap when aluminum cylinder is used
- Solvita® soil life respiration test (paddles)
- Soil thermometer or controlled room temperature
- Small plastic bucket for each group of students
- Baggies with a zipper closure

Laboratory Steps

When soils are mixed, respiration temporarily increases because of the aeration caused by mixing. This is similar to the temporary increase in respiration caused by tillage. As oxygen availability increases, organic matter breaks down quicker.

Consider using an intact soil core in the 3-inch diameter aluminum cylinder rather than mixing soil. An intact core better reflects respiration for no-till applications, while a mixed sample will better reflect respiration either immediately after tillage or post tillage (at least one day after mixing). To get an accurate comparison of different management systems, several soil samples representing different management systems can be compared.

Step-by-Step Procedure

1. Soil Sampling - Gather a minimum of 10 small samples from an area that represents similar soil type and management history with a probe from the surface 0-6 inch depth. Place the samples in the small plastic bucket. Repeat this step for each sampling area.

   (Soil respiration is variable, both spatially and seasonally, and is strongly affected by organic matter, manure applications, oxygen levels, soil moisture, salinity and soil temperature. Use fresh soil samples, gathered just before the test.)

2. Mixing - Mix soil in the plastic bucket just well enough to be homogeneous and remove roots, residue, large stones and residues from sample and place in a labeled plastic zip bag.

3. Add Water if Needed - The sample should have ideal moisture (near field capacity) for growing conditions. If field conditions are dry it is best to add water 24 hours prior to sampling. If needed, water can be added prior to starting the test in the classroom.

4. Put Sample Into Solvita® Jar - Shortly after sampling put moist mix of soil up to fill line in the Solvita® jar. As you fill, tap the bottom of the jar on a hard surface to ensure there are no voids.

5. Use the Color Gel - Insert color gel paddle into soil with the gel facing out next to the clear side of the jar. Be careful not to jostle or tip the jar. Screw the lid on very tightly and record the time on the lid. Keep the jar in the classroom at a controlled temperature of 68-75 degrees Fahrenheit and out of sunlight for 24 hours.

6. Read and Record Results - Read gel color after 24 hours and record results on Table 3.

7. Answer discussion questions and complete interpretations section of Table 3. Refer to Solvita® soil test instructions for additional information and interpretations.

Interpretations

Respiration levels reflect soil health based on the level of carbon dioxide respiration. Rates are impacted by the health of soil, soil organic matter content, and can be used to approximate quantity of nitrogen released per year in an average climate. The rate of carbon dioxide released is expressed as CO_2-C lbs/acre-3”/day.

High soil respiration rates are indicative of high biological activity. This can be a good sign of a healthy soil that readily breaks down organic residues and cycles nutrients needed for crop growth. Solvita® response may go from an inactive condition (0-1 blue-gray) to a very active state (3.5-4.0 green-yellow) as soil respiration increases from desirable management measures such as diverse crop rotations, and no-till.

In some cases, heavily manured soils or soils high in organic content can attain a very high rate (5 yellow). This can be detrimental when decomposition of stable organic matter occurs. It is generally desirable to have at least green color 3. It typically takes several years for a soil to improve from a low biological status to a more active one. With proper residue management, diverse crop rotations, organic matter additions and avoidance of destructive tillage practices, the time to reach a more optimum condition is shortened.

Table 2. Basic soil biological health

Solvita Test - Color/Colorimetric Number				
0-1 Blue-Gray	1.0-2.5 Gray-Green	2.5-3.5 Green	3.5-4.0 Green-Yellow	4-5 Yellow
Soil Respiration Activity				
Very Low Soil Activity	Moderately Low Soil Activity	Medium Soil Activity	Ideal Soil Activity	Unusually High Soil Activity
Associated with dry sandy soils, and little or no organic matter	Soil is marginal in terms of biological activity and organic matter	Soil is in a moderately balanced condition and has been receiving organic matter additions	Soil is well supplied with organic matter and has an active population of microorganisms	High/Excessive organic matter additions
***Approximate Level of CO_2 - Respiration**				
<300 mg CO_2/kg soil/wk	300-500 mg CO_2/kg soil/wk	500-1000 mg CO_2/kg soil/wk	1000-2000 mg CO_2/kg soil/wk	>2000 mg CO_2/kg soil/wk
<9.5 lbs CO_2- C/acre-3" d	9.5-16 lbs CO_2- C/acre-3"d	16-32 lbs CO_2- C/acre-3"d	32-64 lbs CO_2- C/acre-3"d	>64 lbs CO_2- C/acre-3" d
Approximate Quantity of Nitrogen (N) Release Per Year (Average Climate)				
<10 lbs/acre	10-20 lbs/acre	20-40 lbs/acre	40-80 lbs/acre	80->160 lbs/acre

*Source: Doran, J. (2001) USDA-ARS Soil Health Institute correlation of Solvita® and field soil respiration. Calculations based on a 3-inch soil core (7.6 cm).

Table 3. Soil respiration levels and interpretations.

Sample Site	Median 24-hr Soil or Room Temp.	Time-frame	Start Time	End Time	Gel Color & Colorimetric Number	Soil Activity Rating (Table 1)	Avg. Respiration Level lbs CO_2-C/acre-3"/d	Quantity of N Released lbs/ac/yr

What did you expect in terms of the soil respiration levels?

What surprised you about the soil respiration levels?

What do you expect to happen to the soil organic matter based on the soil respiration rates? (improve, decline, remain the same) Why?